Radon Reduced Laboratory

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The radon free laboratory utilizes a charcoal adsorption system, a radon monitoring and measurement system, an hermetically sealed radon-impermeable laboratory, an internal dust free clean room, and a set of machine tools and laboratory apparatus that has been certified radon-emitter free.

Radon Adsorption System

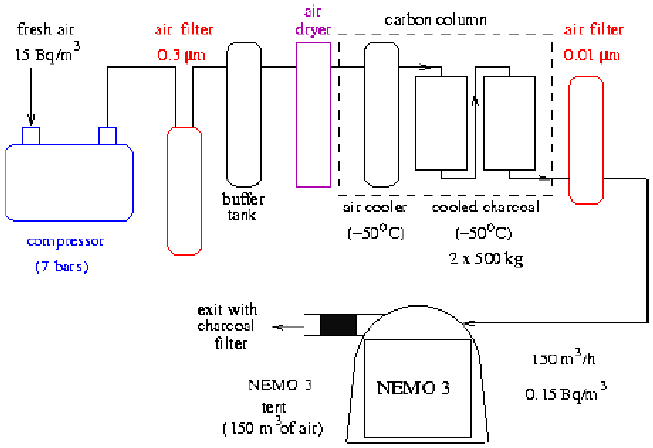
The radon adsorption system is modeled after the Nemo system, shown in Figure 1, with some small changes to allow for investigating techniques to improve performance. Two proposed configurations for our radon-reduced system are shown in Figure 2. The configuration on the left is very similar to the Nemo system, and is known to perform well. The configuration on the right (allows one column to purge, while the first is in use. This has several advantages, paramount is the likelihood of a much lower radon level. For the Nemo system, measured reduction values are derived that are equal to 830 (this is simply the ratio of the quoted input Rn levels, 15 Bq/m^3, and the output level of 0.018 mBq/m^3). From this, we can work out the time *t* it takes a radon atom to traverse the columns, since the factor of 830 presumably comes from radon decay. Thus, the reduction factor, *f*, is related to the half-life $t_{1/2}$ and the traversal time *t* by $f = 2^{t/t_{1/2}}$. Given the radon halflife 3.823 days, we find $t = 37$ days.

For the swing configuration, if the charcoal was absolutely free of uranium chain daughters, then in principle the air that comes through the column is completely radon free. The extra complication are the lines, valves and control system necessary to reconfigure the system, and the vacuum pump. The vacuum pump is a relatively small roots blower, which we specify below. (One could equivalently use a small compressor inside the clean room, but we prefer to keep as much mechanical apparatus as we can outside the radon-free volume.) The speed at which radon flows through the column changes by a factor of 32 in going from -50C to 20C, and therefore we can purge a column in a small fraction of the time it takes to load it. Using the same columns as in the Nemo configuration, each column takes about 18 days to load (as in Figure 1, they run 2 columns in series); at the same volume flow rate we could purge in 12 hours. We would expect that it makes more sense to do this over a longer period of time- say at 10% of the volume flow rate. Another advantage of the purging configuration is that it should be more tolerant of humidity, since the column is periodically dried.

We propose to build a system that allows either configuration, and to test which gives the best performance. We outline each element of the system in detail in the sections below.

Free-Radon air factory

Principe:
Air circulation (150 m³/h) trough a column of charcoal cooled down at -50°C



The specifications of the radon trapping facility are :

- Compressor (7 bars)
- filtration with oil separator (0.03 µm) and dust separator (0.1 µm)
- Air Dryer with a dew point -70°C for 8.5 bars -30°C at maximum value
- Cooling unit
- Two adsorption columns, with internal diameter of 600 mm and 3 m high
- Charcoal: activated carbon 2x500 kg

The Rn level at exit of the column: 18 mBq/m³ ⟹ air sent into the tent

Figure 1. The Modane radon reduction system

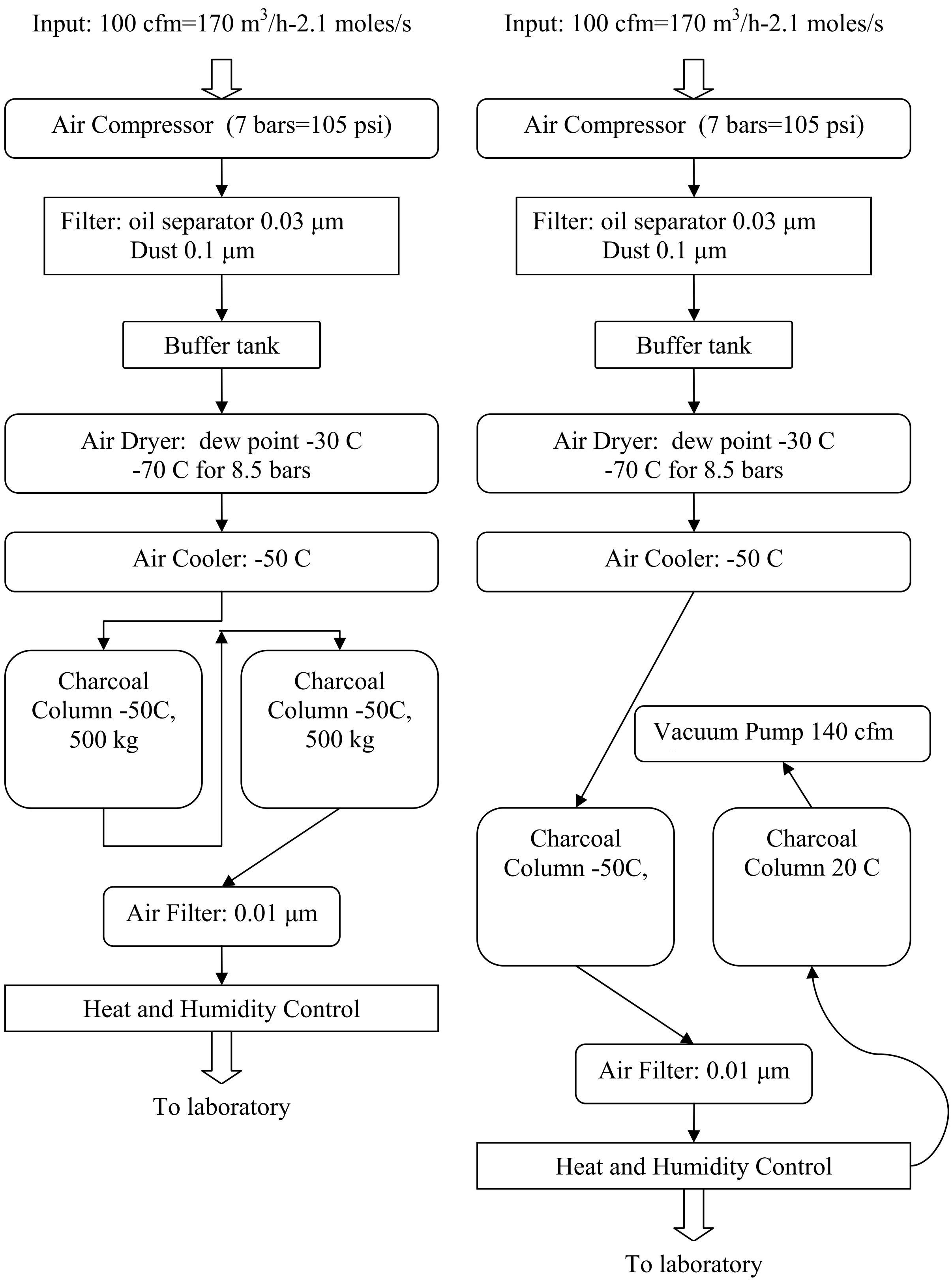


Figure 2. The radon adsorption system. Two very similar configurations are shown. On the left is a straightforward duplication of the Nemo system. On the right, we configure it as a pressure/temperature swing system, in which one column is purged as the other is used.

1. ***Compressor***

   Standard industrial air compressor.

   15 cfm at 105 psi

   100% duty factor

   3 phase power (best, but not necessary)

   For example McMaster-Carr 4364K4 runs at 22.6cfm up to 175 psi, 22 A @230 Volts 3 phase (includes tank) US$2052.42

   Coarse filter on input

2. ***Air Filter***

   Standard industrial air and oil filter (such as McMaster Carr 59185K61)

3. ***Buffer tank***

Probably part of compressor. Compressor is regulated to maintain pressure in buffer tank at 105 psi.

4. ***Air Dryer***

First stage:standard aftercooler (water cooled), moisture separator, and desicant (silica-gel) air dryer.

Need R&D into second stage to get very low humidities.

5. ***Air Cooler***

Refrigerator: Cooling capacity required is 4.3 kW (15000 btu/hour or 1.2 tons) to -50 C. Specify at about twice the nominal cooling power.

Needs to be able to cool air and charcoal columns.

Probably needs water cooling, 3 phase power (look at http://www.edwards-eng.com/pdf/CLL-Series.pdf, although this is almost certainly overkill)

This can drive the design. Going to -40C might be a lot cheaper and require less power, but it cuts the punch through time in the charcoal columns by a factor of two.

6. Charcoal Columns

Attached, as an appendix, is a conference proceeding by Strong and Levins, in which they investigate various charcoal columns, as a function of temperature, humidity, charcoal properties, velocity, etc. It turns out that the Nemo column behaves very much as predicted by this set of measurement. The time it takes for radon to move through the column is given by

$$\tau = \frac{k_a m}{F} = \frac{T k_a \rho_b L}{273 \mu_s} \tag{1.1}$$

Where τ is the punch through time, k_a is the dynamic absorption coefficient (m^3(STP)/kg), m is the mass of charcoal (kg) in the bed, F is the flow rate in m^3(STP)/s, T is the absolute temperature, L the length (height) of the column, and μ_s the superficial velocity. I am not familiar with the term superficial velocity, but as far as I can tell it is simply the mass flow rate divided by the area of the column and the density of the gas- the actual velocity of a small gas volume will be faster because some fraction of the cross section is filled with charcoal. Pocar points out that changing the pressure of a gas increases the density and the mass flow rate, but doesn't affect μ_s.

The dynamic absorption coefficient is given by

$$k_a = (0.0070S - 3.51)\frac{e^{29000/RT}}{e^{29000/273R}} \tag{1.2}$$

where R is the gas constant (8.3144 J/mol-K) and S is the surface area in m^2/g. (Note that this formula is different from that given in the paper because it changes the sign of the exponential and because it has a normalizing factor in the denominator; these changes are necessary to make the formula agree with figure 5 in Strong and Levins).

The Nemo columns are 3m high, 0.6 m in diameter, so the superficial flow rate is 0.15 m/s, and we find that at -50C and S=1200 m^2/g, $\tau = 48$ days; while for S=1000, $\tau = 31$ days. This agrees very well with the 37 day experimental number.

At room temperature (20C), k_a drops from about 180 to 4.2, and we find that the length of time for radon to move through the column is 1 day. In the swing configuration, we only use half the column, and so the numbers become 18 days to load up a column and 12 hours to purge it at the same superficial velocity. Since we flow at a pressure difference of 7 bar, and purge with a pressure difference of 1 bar, the flow rate will be down by a factor of 7, and it will take 3.5 days to purge the column. (The average pressure is also down by a factor of 5, so we only require 1/35 of the mass flow for purging) . To start the system, one imagines purging with LN boiloff; this would require

$$170\ \mathrm{m}^3/\mathrm{h} \times \frac{1}{35} \times 3.5\ \mathrm{days} \times 24 \frac{\mathrm{hours}}{\mathrm{day}} = 408\ \mathrm{m}^3 \times \frac{1}{700} = 583\ \mathrm{liters\ LN}_2$$

Here 700 is the ratio of gas to LN volume.

In the swing configuration, one would probably choose smaller columns- there is something nice in being able to turn on after about a day of purging (it also requires a smaller volume of LN to purge). I would suggest something like a factor of five decrease in volume- which would allow us to purge in less than a day. Given the 2 configuration design, I would suggest a third smaller column, which will be used to start up the system quickly, to recover from any faults, and which we would keep purged as we were cycling the other two columns.

Charcoal: clean, largest surface area, smallest mass mean diameter (see Strong and Levins)

Need ability to cool down columns to operating temperature and to warm them up to room temperature. Control system should be certain column is cold before flowing air through it

Require source of clean nitrogen/air to purge and cool columns.

Radioactively clean charcoal—see Heuser (Rau).

7. Air filter

0.01μ, in order to prevent charcoal dust from entering the clean room.

8. Vacuum Pump

Probably a roots blower, with a backing pump. The maximum desirable flow rate is 1/7*100 cfm=14 cfm; if the blower is running at 1/10 atmosphere this requires 140 cfm displacement.

9. Temperature and Humidity Control

Bring air to room temperature (25C)

Humidify the air to 40% RH

10. Monitoring and Controls

The monitoring system for the radon stripper is shown in figure Figure 3. We want constant monitoring and automatic control of the running system.

Failsafe operation

Automatic control of purging and flow of gas.

Recovery from power failure

Monitoring laboratory itself (Rn, O2, CO2)

Monitoring clean room (dust count, Rn, filter condition, air flow)

Monitoring air radon emanation chambers (8 x Rn)

Needs to be running before laboratory is built (for stripper, emanation chambers)

Room for expansion

Radon monitors: Need some development (John Golightly thesis)

> **Windowless Silicon detector with electrostatic bias to measure radon, Po218, Po214- want to record energy and time of each event to microsecond resolution.**
>
> **Can use forward/reverse biased detectors**
>
> **Need large volumes, flow sampling to measure Rn output of stripper, Rn levels in lab and in chambers**
>
> **Calibrated Rn source for testing (Pylon)**

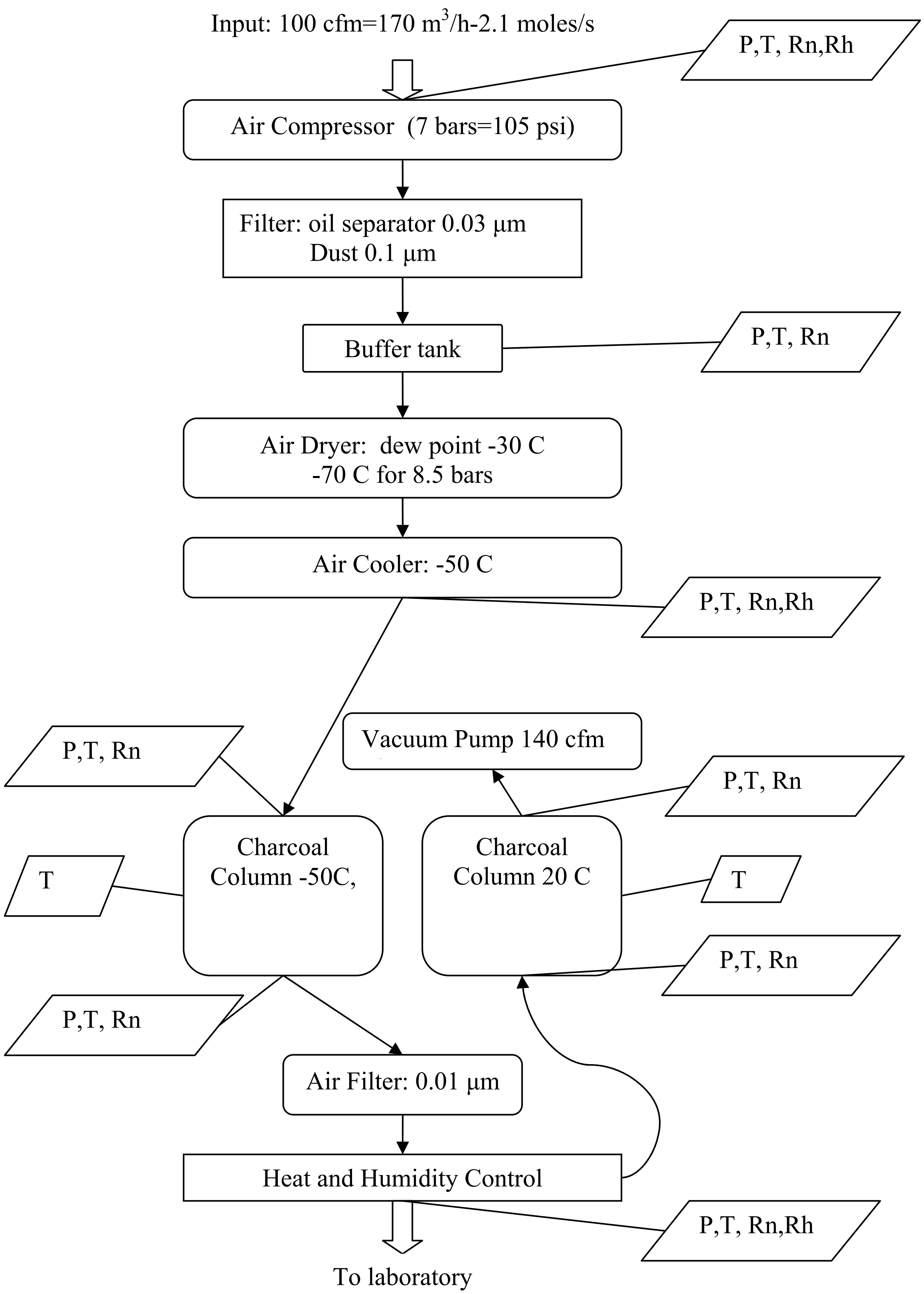


Figure 3. Monitoring points in radon reduction system. P=Pressure, T=Temperature, Rn=Radon, Rh=Relative Humidity

11. Laboratory walls